1.1 DC Power Supplies

Most of the electronic devices and circuits are operated by DC power supplies. It consist of main four stages explained below.

Step down transformer: It is a device that has two coil windings: primary and secondary used to convert a high AC voltage (230V/ 50Hz) to a required low AC voltage.

Rectifier: It is a device has one or more diodes, converts secondary AC voltage to pulsating DC.

Smoothening Filter: It is a circuit used to remove fluctuations (ripple or ac) present in rectifier output. Example: Capacitor filters, LC filters, π- filters, etc..

Voltage Regulator: Voltage regulator is a circuit which provides constant DC output voltage irrespective of changes in load current or changes in input voltage.

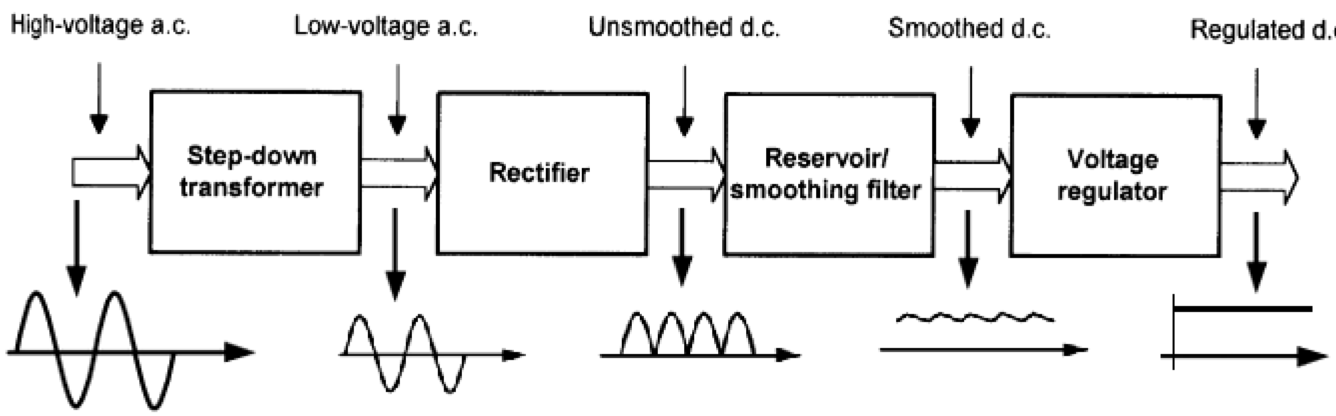
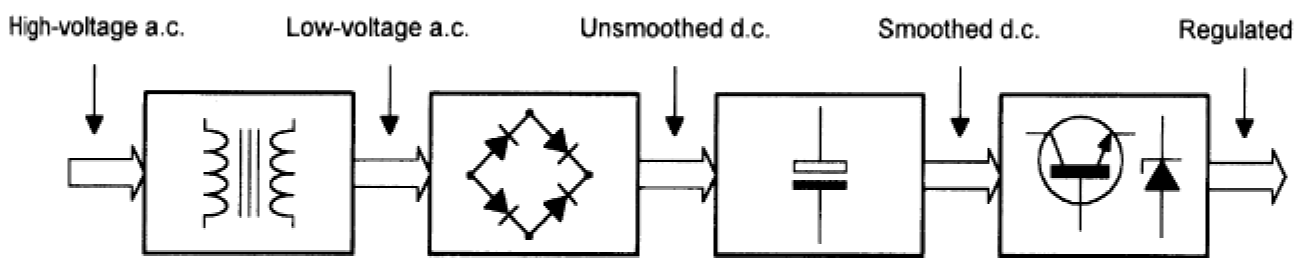


Fig.1. Block diagram of a DC power supply

Fig. 2, shows important electronic components that are used in the block diagram in fig. 1. Step-down transformer is made of iron core, feeds a rectifier. Rectifier output is applied to a high value capacitor to minimize ripples. Capacitor filter charges as the rectifier output voltage increases until its peak value. When the voltage value reduces, it discharges gradually through the regulator. Finally, a series transistor regulator and zener diode provides a constant output DC voltage.



Step-down Transformer **Rectifier** **C Filter** **Voltage regulator**

Fig.2. Block diagram of a DC power supply showing principal components used in each stage

1.1.1 Rectifiers

Semiconductor diodes are commonly used as rectifiers. It converts AC voltage into rippled DC voltage. There are two types: Half-wave and full wave rectifiers.

Fig. 3 shows *half-wave* rectifier that allows one half of an AC waveform to pass through to the load. AC voltage (240V r.m.s) is applied to the primary of step-down transformer (T1). The secondary of T1, reduces to 12V r.m.s. (Taking turns ratio: 240: 12 = 20:1). Diode D1 will allow current only in positive half cycle being forward biased and operates as a closed switch, see fig. 3(b). For negative half cycle, current will not allow passing through D1, because it is reverse biased and act like an open switch, see fig. 3(c).

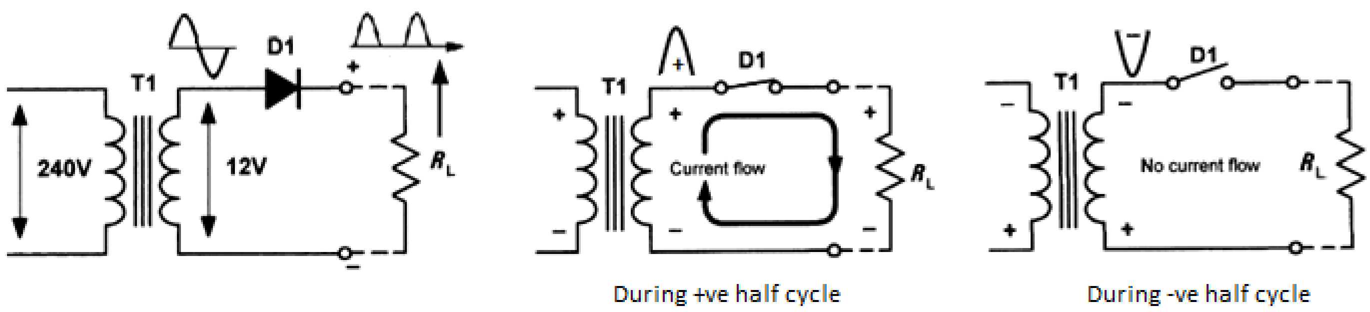


Fig.3. (a) Half wave rectifier circuit (b) For + ve half cycle (closed switch) (c) For - ve half cycle (open switch)

The switching action of D1 results in pulsating output voltage available at load resistor (R_L). During positive half cycle, silicon diode will drop 0.6V to 0.7V as forward threshold voltage. During negative half cycle, D1 is reverse biased, hence secondary of T1 peak voltage will be dropped across it.

Analysis During +ve half cycle:

Secondary of T1 = 12V r.m.s voltage
Peak voltage across secondary windings:
$V_{peak} = 1.414 \times V_{rms}$
$= 1.414 \times 12 = 16.968V \sim 17V$
Silicon diode drop voltage = 0.7V
Actual output voltage across load R_L
$= 17 - 0.7 = 16.3V$

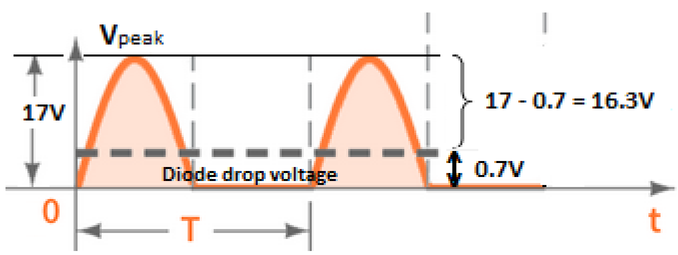


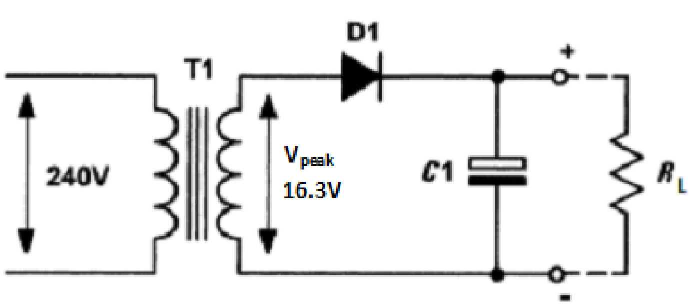
Fig.4 Illustration of actual output voltage across load R_L

1.1.3 Smoothing (Reservoir) circuits

Smoothening circuit is a capacitor filter C1 connected in parallel to the load R_L as shown in the fig.5. It is used to remove fluctuations (ripple or ac) present in rectifier output. When 240V AC voltage is applied to primary of T1, its secondary reduces to 12V r.m.s value and peak value is 16.3V.

During +ve half cycle of secondary voltage, diode is forward biased, C1 charges as the rectifier output voltage increases to its peak value (16.3V).

When the rectifier voltage starts to decrease, C1 discharges slowly through the load R_L, until the next +ve half cycle is met.



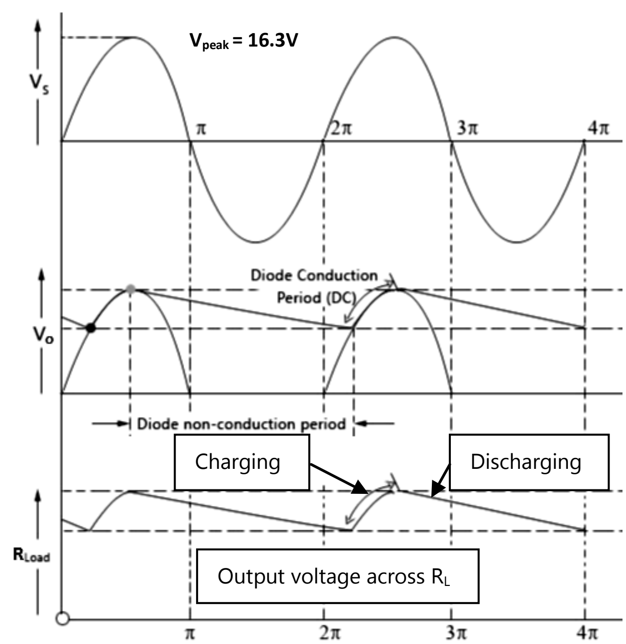


Fig. 5. a) Half wave smoothing circuit **b) Input and output wave forms**

Charging Time of C1 to the peak value = R_{series} x C1	Discharging Time of C1 = R_L x C1
$R_{series} = R_{secondary\ winding} + R_{diode} + R_{wiring\ and\ connections}$	Practically, R_L is very much larger than R_{series}
Hence C1 charges quickly as soon as diode conducts.	Hence C1 discharges slowly through R_L.

Capacitor as reservoir: C1 stores charge during +ve half cycle of secondary V_{peak} and releases it during –ve half cycle, maintaining reasonably constant output voltage across R_L. This causes to a small DC ripples at the output. The DC ripples can be drastically reduced by choosing a larger C1 value in place of smaller value.

Improved ripple filters --

In filers the value of the capacitor plays an important role in determining the output ripples and the average DC level. If the capacitor value is high, the amount of charge it can store will be high and the amount it discharges will be less. Thus the ripples will be less and the average dc level will be high.

Limitations of C filter

If the capacitor value is increased to a very high value, the amount of current required to charge the capacitor will be high. So, diodes are subjected to high surge currents. Thus, there is a limit in increasing the capacitor value in half-wave rectifiers.

Refinement of C filter (RC filter)

Additional components R1 and C2 are connected as shown in the fig.6. C1 and C2 offer low reactance to AC components of ripple. In effect R1 and C2 act like a voltage divider and amount of ripple is reduced. But certain amount of DC voltage will drop across R1. The value of C2 is selected in such way that it exhibits negligible reactance at low frequencies (50Hz – 100Hz).

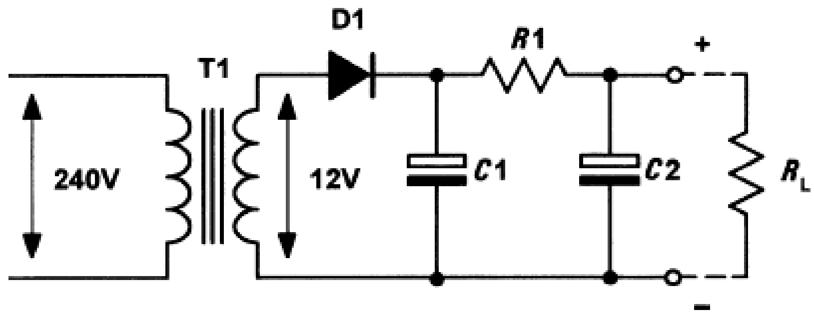


Fig.6. Half wave rectifier with R1 and C2

Amount of ripple reduction is determined by

$$\frac{X_C}{\sqrt{(R_1^2 + X_C^2)}}$$

Where, X_C = reactance of C2.

L-C Smoothing Filter

From the fig.7, at the ripple frequency, C1 exhibits low value of capacitive reactance. Hence it bypasses most of AC components of ripples. L1 exhibits high value of inductive reactance, therefore it allows most of DC components. Further, C1 bypasses remaining AC components offering low value of capacitive reactance. Thus the combined effect of L C greatly reduces the ripples.

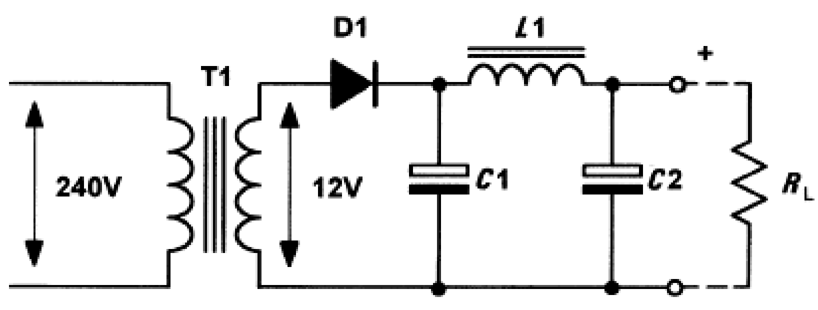


Fig.7. Half wave rectifier with R1 and LC filter

Advantage: Half wave rectifier is cheap, simple and easy to construct.

Disadvantage:

1. Ripple factor is high at the output.
2. Rectification efficiency is quite low, that means, power is delivered only during one half cycle of the input alternating voltage.
3. Transformer utilization factor is low.

1.1.4 Full-wave rectifiers

Full-wave rectifier – there are two types:

- *Bi-Phase or Center Tapped full wave rectifier* - uses two diodes and center tapped power transformer.
- *Bridge full wave rectifier* - uses four diodes and ordinary power transformer.

Bi-phase Rectifier ---

The AC mains (240V) is applied to the primary of T1 which has two identical secondary windings each providing 12V r.m.s, as shown in the fig.8.

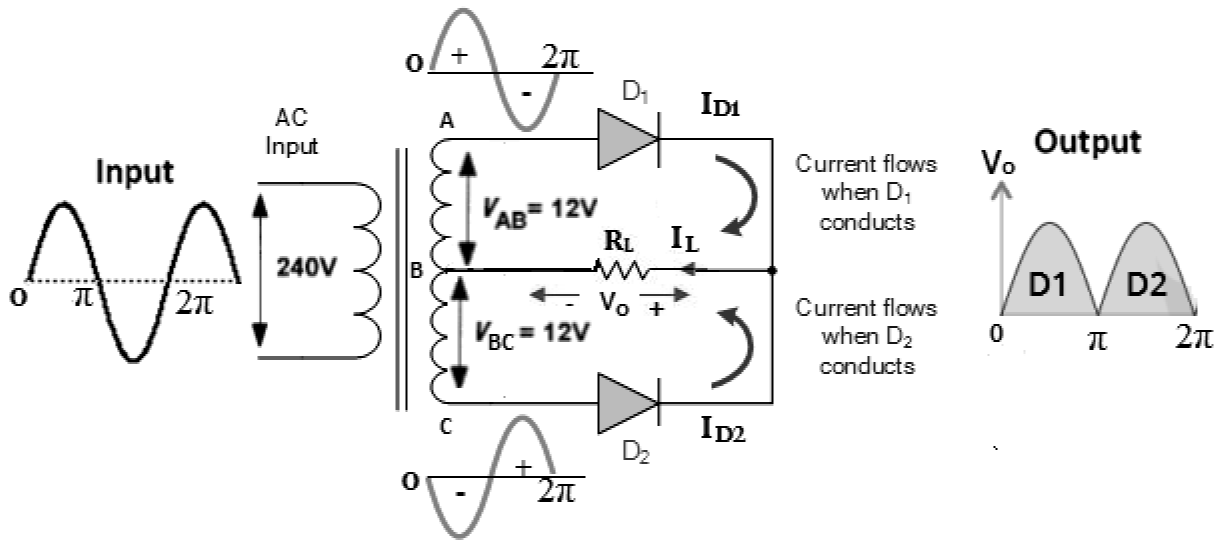


Fig.8. Bi-phase rectifier circuit

On +ve half cycles, point A will be +ve with respect to point B. similarly, point B will be +ve with respect to point C.

D1 will forward bias, acts like a closed switch hence conducts. While D2 will reverse bias, acts like an open switch hence do not conduct. It is as shown in the fig. 9(a).

Thus, D1 alone conducts on +ve half cycles.

On -ve half cycles, point C will be +ve with respect to point B. similarly, point B will be +ve with respect to point A.

D2 will forward bias, acts like a closed switch hence conducts. While, D1 will reverse bias, acts like an open switch hence do not conduct. It is as shown in the fig. 9(b).

Thus, D2 alone conducts on -ve half cycles.

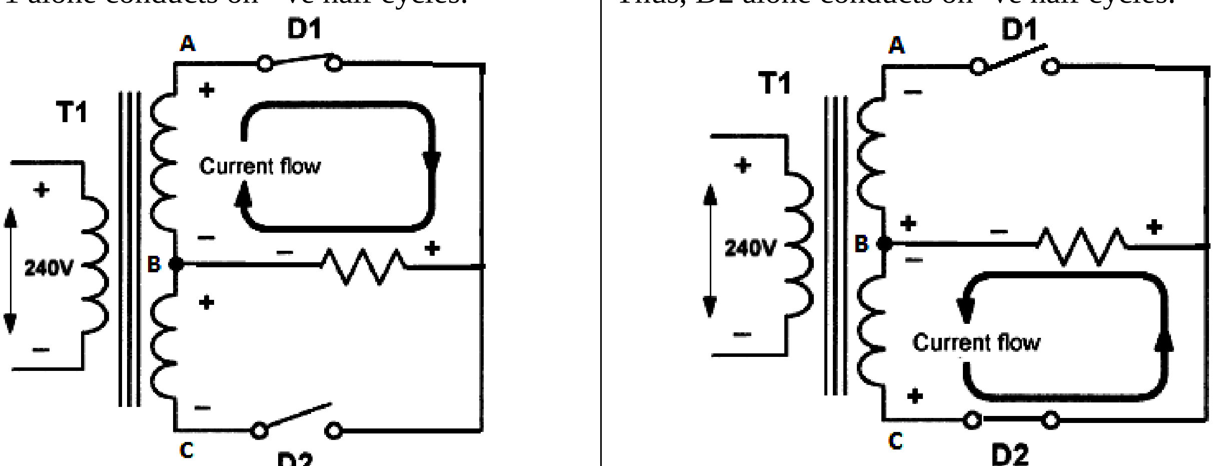


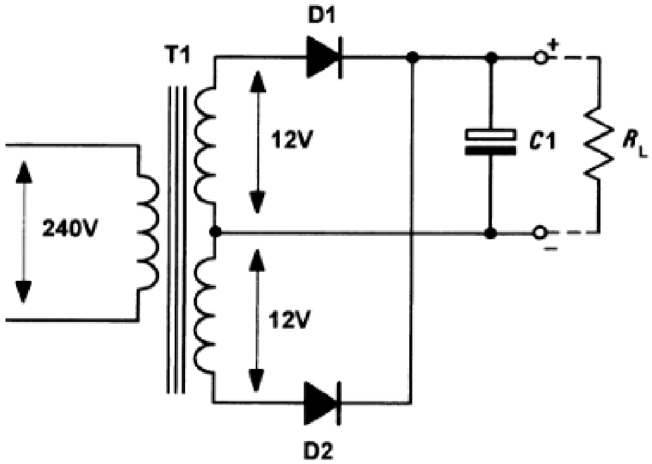
Fig.9. a) Bi-phase rectifier circuit for +ve half cycles **b) Bi-phase rectifier circuit for -ve half cycles**

NOTE: i) V_{peak} produced by each of secondary windings = 17V – 0.7V = 16.3V

ii) Pulses of voltage developed across R_L = 100Hz (if primary is 50Hz)

Bi-phase rectifier with C filter---

Two diodes D_1 and D_2 are used in this circuit. They feed a common load resistor R_L, with the help of a center tapped transformer as shown in the fig.10.



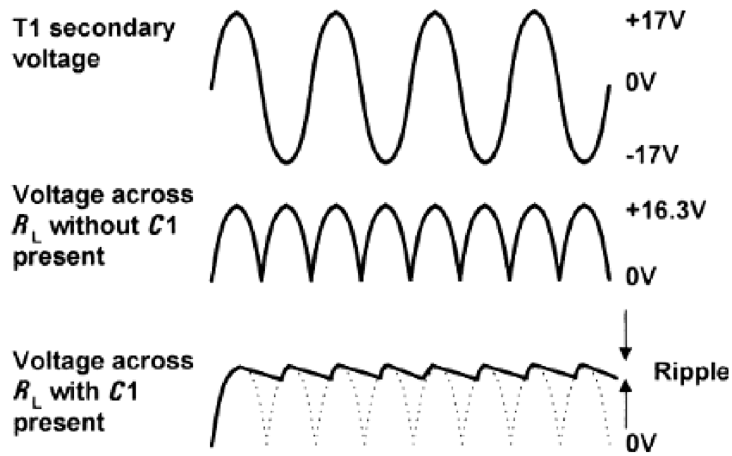


Fig.10. **a) Bi-phase rectifier with C1 filter** **b) Input output wave forms**

When diode D1 conduct, C1 charges to the peak value (16.3V) of the +ve half cycle. When diode D2 is in non-conducting state, C1 discharges slowly through the load R_L. Similarly, when diode D2 conduct, C1 charges to the peak value of the -ve half cycle and C1 starts to discharge during diode D1 non-conducting state. Note that in this case capacitor C1 charge and discharge twice through R_L during one full cycle.

Charging Time of C1 to the peak value = R_{series} x C1

$R_{series} = R_{secondary\ winding} + R_{diode} + R_{wiring\ and\ connections}$

Hence C1 charges quickly as soon as diode conducts.

Discharging Time of C1 = R_L x C1

Practically, R_L is very much larger than R_{series}

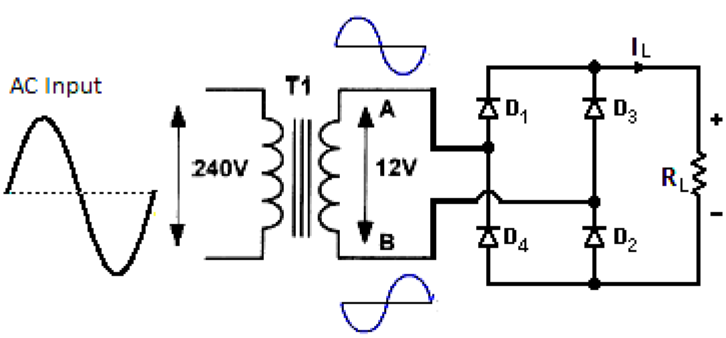
Hence C1 discharges slowly through R_L.

Disadvantages of Bi-phase Rectifier:

- It is difficult to construct and locate the center-tap on secondary winding of the transformer.
- The diodes used must have high PIV.

Bridge Rectifier Circuits---

Bridge full wave rectifier employs four diodes, but only two diodes will conduct during each half cycle. The AC mains (240V) is applied to the primary of T1 and secondary windings providing 12V r.m.s, as shown in the fig.11.



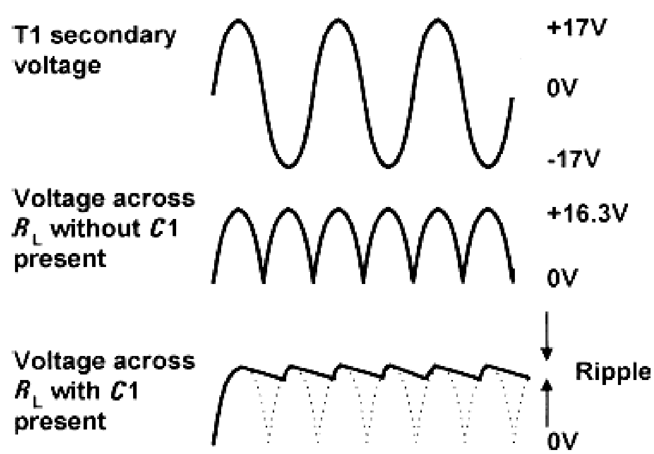


Fig.11. **a) Bridge rectifier** **b) Input output wave forms**

<u>During **positive half cycle**:</u>

Point A will be +ve with respect to point B, then diodes D_1D_2 are forward biased act like closed switches, and hence conduct. While, diodes D_3D_4 are reverse biased act like open switches, hence do not conduct.

<u>During **negative half cycle**:</u>

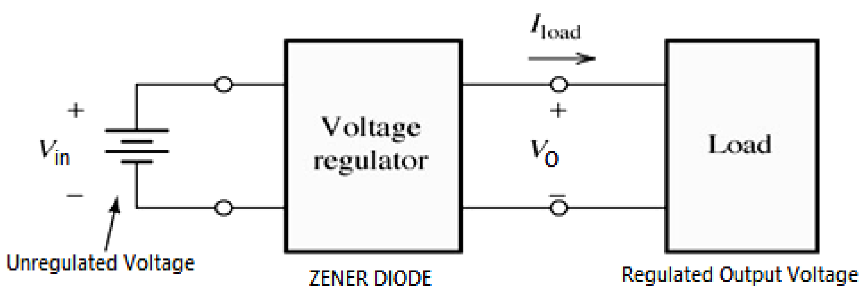
Point B will be +ve with respect to point A, then diodes D_3D_4 are forward biased act like closed switches, and hence conduct. While, diodes D_1D_2 are reverse biased act like open switches, hence do not conduct.

In both +ve and –ve half cycles current I_L flow through load resistance R_L. The complete input-output voltage waveforms of the bridge full wave rectifier are shown in fig. 11(b).

Bridge rectifier with capacitor filter works very similar to that of bi-phase rectifier circuit.

1.1.5 Voltage Regulators

Voltage regulator is a device by which output voltage $V_{O,}$ is maintained constant regardless of change in the input voltage V_{in} or load $R_{L.}$ The circuit diagram of the zener diode as a simple voltage regulator is shown in the fig.12.



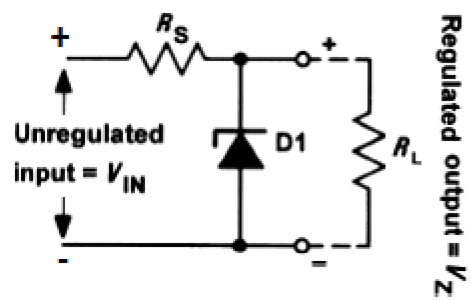


Fig.12. a) Simple block diagram of voltage regulator b) Zener diode shunt voltage regulator

The series resistor, R_S is connected in the circuit to limit the current through the zener diode to a safe value when load R_L is disconnected. Also, the voltage drop across it is a part of unregulated input voltage, V_{in}. When R_L is connected, zener current I_Z will reduce as current ($I = I_z + I_L$) is split into load R_L.

Output voltage $V_{O,}$ remains constant until regulation fails. Regulation fails at a point at which potential divider formed by R_S and R_L produces lower voltage than V_Z voltage.

$$V_Z = V_{IN} \times \frac{R_L}{R_L + R_S}$$

Series Resistor value (ohms) = (V_i – V_z) / (Zener current + load current). Maximum value of R_S can be calculated as,

$$R_{Smax} = R_L \times \left(\frac{V_{IN}}{V_Z} - 1\right) \ and \ R_{Smin} = \frac{(V_{IN}V_Z) - V_Z^2}{P_{Zmax}}$$

Also,

$$R_{max} = \frac{V_{i(min)} - V_z}{I_{L(max)} + I_{z(min)}} \quad and \ R_{min} = \frac{V_{i(max)} - V_z}{I_{L(min)} + I_{z(max)}}$$

The zener diode conducts the least current ($I_{z\,(min)}$) when the load current I_L is maximum and it conducts the maximum current when the load current is minimum, $I = I_z + I_L$.

The power dissipation of Zener diode is described as:

$$P_z = V_z I_{z(max)}$$

1.1.6 Output resistance and voltage regulation

In a perfect power supply output voltage (V_O), remain constant regardless of the current taken by the load. However practically, V_O reduces as load current increases. This is due to *internal resistance* (r_i) of the power supply. That means, this internal resistance appears at the output of the power supply. It is defined as

$$R_o = \frac{Change\ in\ V_O}{Change\ in\ I_L} = \frac{dV_O}{dI_L}$$

The regulation of a power supply is given by

$$regulation = \frac{Change\ in\ V_O}{Change\ in\ V_{IN}} \times\ 100\ \%$$

Ideally, the value of the regulation should be very small. Various regulators produce value of regulation as tabulated below:

Sl.No	Type of regulator	Regulation in %
1	Zener shunt	5 to 10
2	Sophisticated circuits based on discrete components	1 to 5
3	Integrated Circuit (IC)	Lesser than 1%

1.1.7 Voltage multipliers

Voltage multiplier is a modified capacitor filter circuit that delivers a dc voltage twice or rnore times of the peak value of the input AC voltage. Such power supplies are used for high-voltage and low-current devices such as cathode-ray tubes (the picture tubes in TV receivers, oscilloscopes and computer display).

Voltage Doubler

The circuit diagram for a full-wave voltage doubler is given in the fig.13. Assume in the beginning all capacitors are cleared (stored 0V).

During the +ve half cycle of V_{IN} voltage, diode D_1 gets forward biased (conducts) and charging the capacitor C_1 to a peak voltage V_{peak} with polarity indicated in the figure, while diode D_2 is reverse-biased and does not conduct. During the -ve half-cycle, diode D_2 being forward biased (conducts) and charges the capacitor C_2 with polarity shown in the figure, while diode D_1 does not conduct.

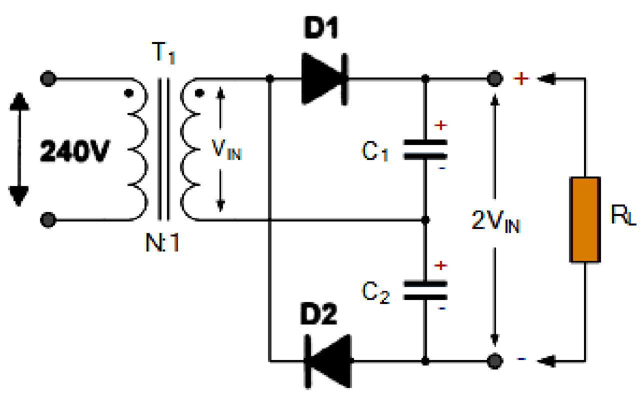


Fig.13. Voltage Doubler circuit

With no load connected to the output terminals, the output voltage will be equal to sum of voltages across capacitors C_1 and C_2. i.e., $V_{C1} + V_{C2} = 2\ V_{IN}$

When the load is connected to the output terminals, the output voltage V_L will be less than 2 V_{IN}.

$$V_{out} = 2V_{IN} - \text{voltages drop across diodes}$$

Voltage Tripler

The voltage doubler can be extended to produce 3 times voltages (Tripler) using the cascade arrangement shown in Fig. 14. Here C1 charges to the positive secondary voltage V_{IN}, while C2 and C3 charge to twice the positive secondary voltage. The result is that the output voltage is the sum of the voltages across C1 and C3 which is three times the voltage that would be produced by a single diode.

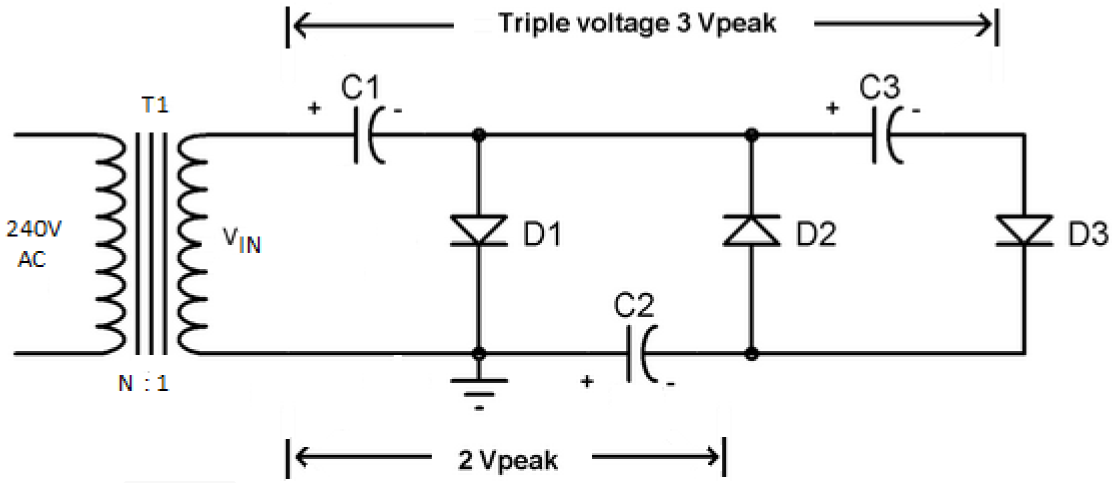


Fig.14. Voltage Tripler circuit

Assume in the beginning all capacitors are cleared (stored 0V).
During the first positive half cycle, diode D1 conducts (forward biased) and capacitor C1 gets charged the V_{IN} of secondary.
During the negative half cycle, diode D2 is forward biased and diode D1 is reverse biased. D1 does not let discharge the capacitor C1, so voltage across C1 = V_{IN}. The capacitor C2 gets charged with the combined voltage of C1 (V_{IN}) and negative peak voltage of secondary voltage, so, C2 gets charged to $2V_{IN}$.

During the second positive half cycle, diode D1 and D3 conduct and D2 get reverse biased. So, the capacitor C2 charges the capacitor C3 up to $2V_{IN}$. Now, as we can see that the capacitors C1 and C3 are in series so the total voltage across these capacitors is $V_{IN} + 2V_{IN} = 3V_{IN}$. This is how the tripled value of the applied voltage available at the output. Practically, some of the voltage drops across the diodes.

$$V_{out} = 3V_{IN} - \text{voltages drop across diodes}$$

1.2 Amplifiers

1.2.1 Types of amplifiers

Amplifier is an electronic circuit which increases the amplitude of its input signal without changing other parameters.

AC coupled amplifiers

In AC coupled amplifiers, stages are coupled together in such a way that DC levels are blocked and only the AC components of a signal are transferred from stage to stage.

DC coupled amplifiers

In DC (or direct) coupled amplifiers, stages are coupled together in such a way that stages are not isolated to DC potentials. Both AC and DC signal components are transferred from stage to stage.

Large-signal amplifiers

Large-signal amplifiers are designed to cater for appreciable voltage and/or current levels (typically from 1 V to 100 V or more).

Small-signal amplifiers

Small-signal amplifiers are designed to cater for low-level signals (normally less than 1 V and often much smaller). Small-signal amplifiers have to be specially designed to combat the effects of noise.

Audio frequency amplifiers

Audio frequency amplifiers operate in the band of frequencies that is normally associated with audio signals (e.g. the range of human hearing 20 Hz to 20 kHz).

Wideband amplifiers

Wideband amplifiers are capable of amplifying a very wide range of frequencies, typically from a few tens of hertz to several megahertz.

Radio frequency amplifiers

Radio frequency amplifiers operate in the band of frequencies that is normally associated with radio signals (e.g. from 100 kHz to over 1 GHz). Note that it is desirable for amplifiers of this type to be frequency selective and thus their frequency response may be restricted to a relatively narrow band of frequencies (see fig.15).

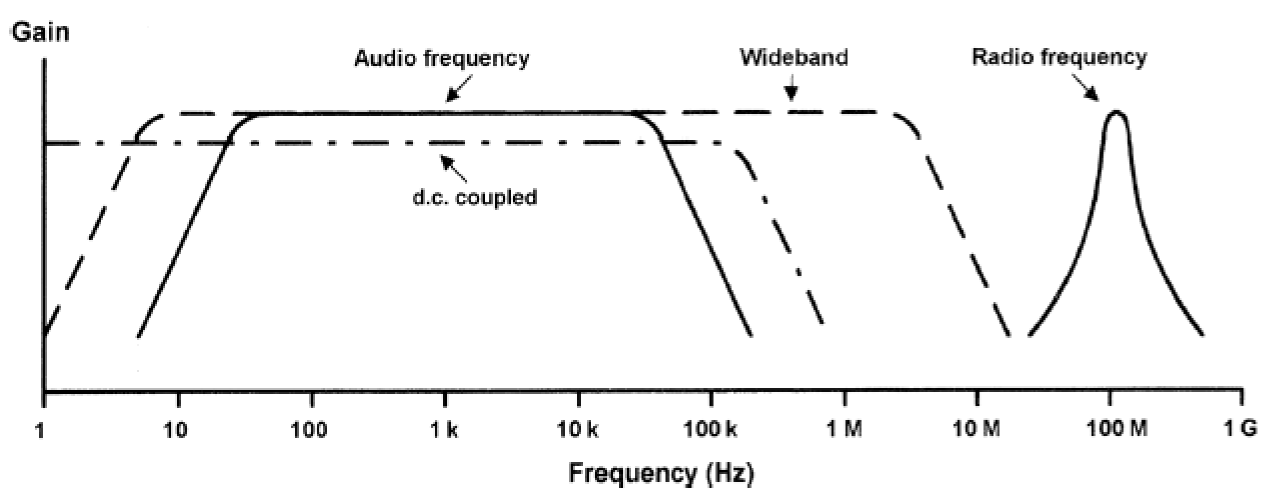


Fig.15. Frequency response and bandwidth (output power plotted against frequency)

Low-noise amplifiers

Low-noise amplifiers are designed so that they contribute negligible noise (signal disturbance) to the signal being amplified. These amplifiers are usually designed for use with very small signal levels (usually less than 10 mV or so).

Voltage Amplifier

The purpose of a voltage amplifier is to make the amplitude of the output voltage waveform greater than that of the input voltage waveform.

Current amplifier

The purpose of a current amplifier is to make the amplitude of the output current waveform greater than that of the input current waveform.

Power amplifier

In a power amplifier, the product of voltage and current (i.e. power = voltage x current) at the output is greater than the product of voltage x current at the input.

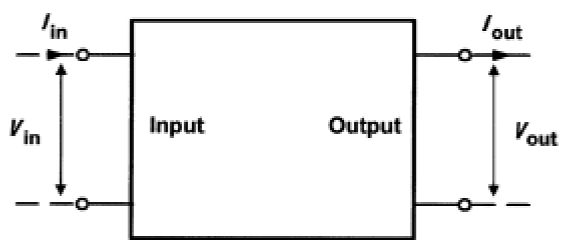
1.2.2 Amplifier Parameters

Gain: The amount of amplification (or gain) is simply the ratio of output voltage to input voltage, output current to input current, or output power to input power (see Fig. 7.2). These three ratios give, respectively, the voltage gain, current gain and power gain.

$$\text{Voltage gain}, A = \frac{V_{out}}{V_{IN}}$$

$$\text{Current gain}, A = \frac{I_{out}}{I_{IN}}$$

$$\text{Power gain}, A = \frac{P_{out}}{P_{IN}}$$



Power is the product of current and voltage ($P = I\,V$),

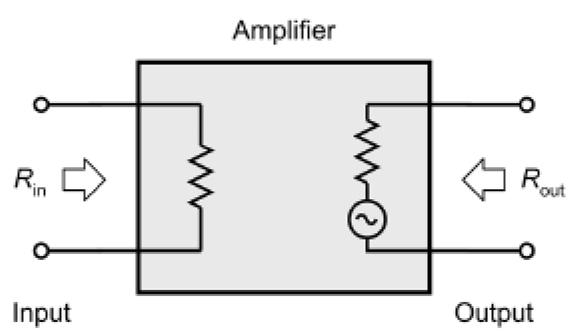
$$A_p = \frac{P_{out}}{P_{in}} = \frac{I_{out} \times V_{out}}{I_{in} \times V_{in}} = \frac{I_{out}}{I_{in}} \times \frac{V_{out}}{V_{in}} = A_i \times A_v$$

Input resistance (R_{in}): Input resistance is the ratio of input voltage to input current and it is expressed in Ω. The input of an amplifier is normally purely resistive (i.e. any reactive component is negligible) in the middle of its working frequency range (i.e. the **mid-band**). In some cases, the reactance of the input may become appreciable (e.g. if a large value of stray capacitance appears in parallel with the input resistance). In such cases we would refer to **input impedance** rather than input resistance.

Output resistance (R_{out}): Output resistance is the ratio of open-circuit output voltage to short-circuit output current, measured in Ω.

As with input resistance, the output of an amplifier is normally purely resistive and we can safely ignore any reactive component. If this is not the case, we would once again need to refer to **output impedance** rather than output resistance.

[Note: This resistance is internal to the amplifier and should not be confused with the resistance of a load connected externally]



Frequency response: It is the graph plotted for gain verses input frequency of an amplifier. The frequency response of an amplifier is usually specified in terms of the upper (f_2) and lower (f_1) cut-off frequencies of the amplifier. These frequencies are those at which the output power has dropped to 50% (otherwise known as the **−3 dB points**) or where the voltage gain has dropped to 70.7% of its mid-band value. Fig. 16 show how the bandwidth can be expressed in terms of either power or voltage.

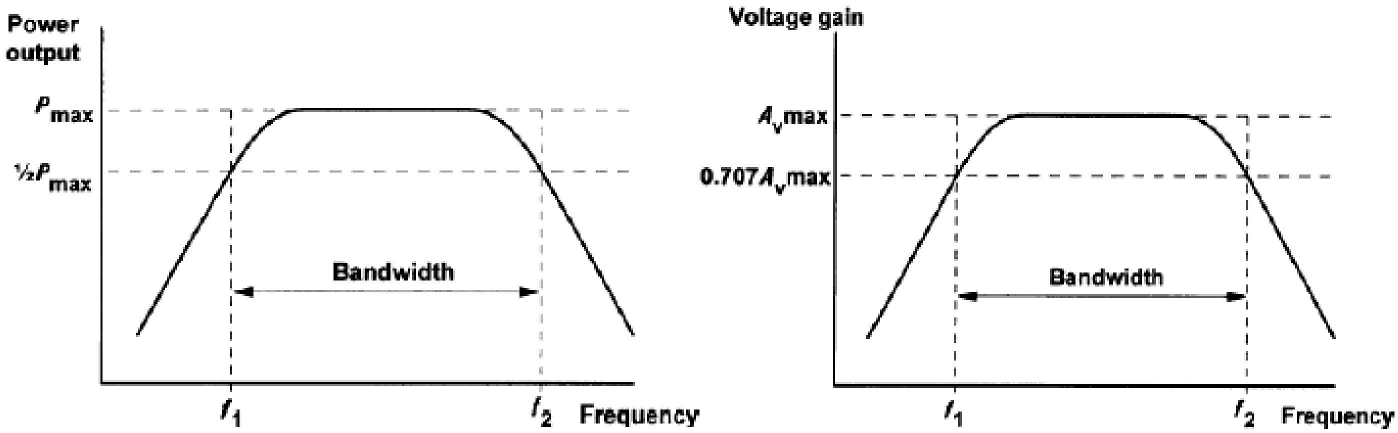


Fig.16. Frequency response and bandwidth a) output power Vs frequency b) output voltage Vs frequency

Bandwidth: The bandwidth of an amplifier is usually taken as the difference between the upper and lower cut-off frequencies (i.e. $f2 - f1$ in Fig.16). The range of frequencies within a band is known as bandwidth.

Example: Audio amplifiers have a flat frequency response (as shown in fig.17) over the audio range of frequencies from 20 Hz to 20 kHz. This range of frequencies, for an audio amplifier is called its Bandwidth, (BW).
The bandwidth of an amplifier must be sufficient to accommodate the range of frequencies present within the signals that it is to be presented with.

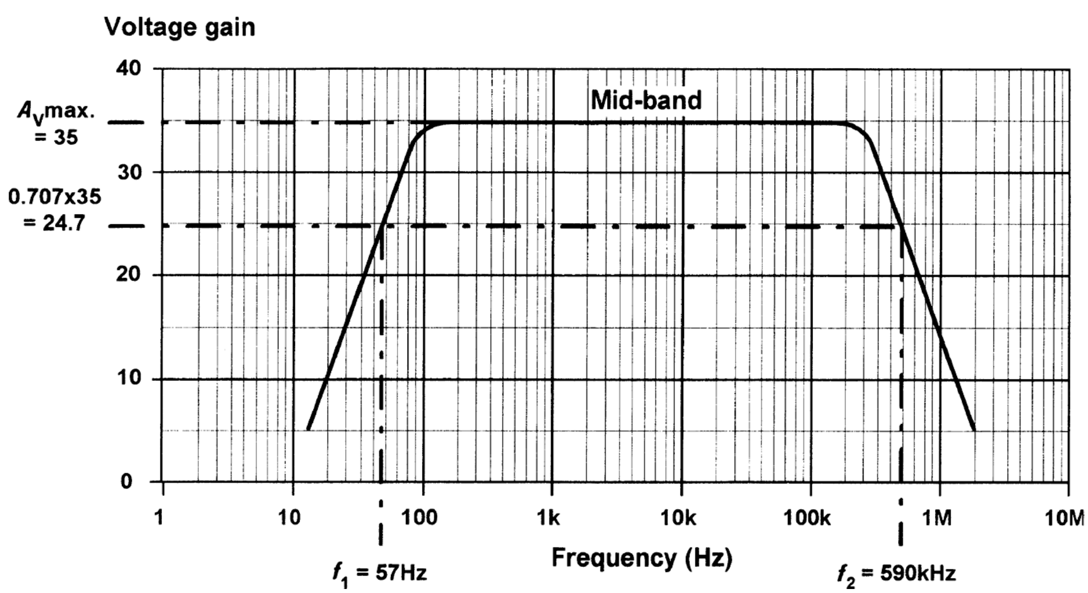


Fig.17. Mid-band voltage gain, upper and lower cut-off frequencies of amplifier with frequency response

Phase shift: Phase shift is the phase angle between the input and output signal voltages measured in degrees. The measurement is usually carried out in the mid-band where, for most amplifiers, the phase shift remains relatively constant. Note also that conventional single-stage transistor amplifiers provide phase shifts of either 180° or 360°.

1.2.3 Negative feedback

Many practical amplifiers use negative feedback in order to precisely control the gain, reduce distortion and improve bandwidth. The gain can be reduced to a manageable value by feeding back a small proportion of the output. The amount of feedback determines the overall (or **closed-loop**) gain. The form of feedback has the effect of reducing the overall gain of the circuit, is known as **negative feedback**.

An alternative form of feedback, where the output is fed back in such a way as to reinforce the input (rather than to subtract from it) is known as **positive feedback**.

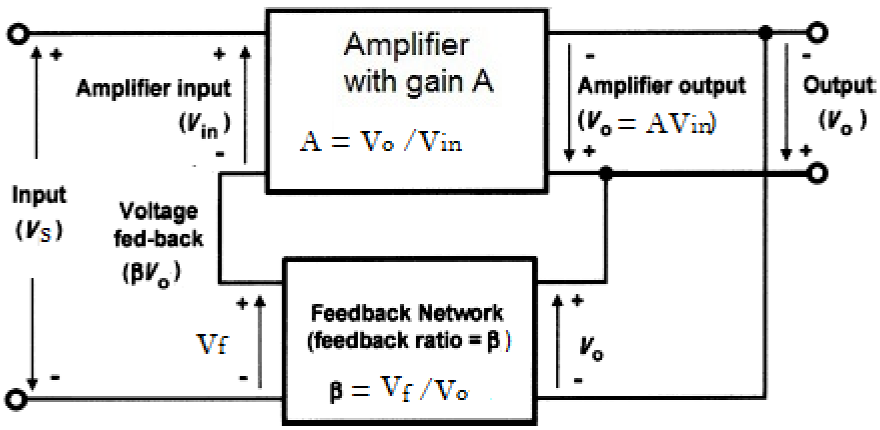


Fig.18. Amplifier with negative feedback applied

$A = Vo/V_{in}$

$Vo = A\,V_{in}$, where $V_{in} = V_S - V_f$

and $V_f = \beta Vo$

$Vo = A(Vs - \beta Vo)$

$Vo = AVs - A\,\beta Vo$

$Vo + A\,\beta Vo = AVs$

$AVs = Vo\,(1 + A\beta)$

So, the equation of overall gain with negative feedback is given by

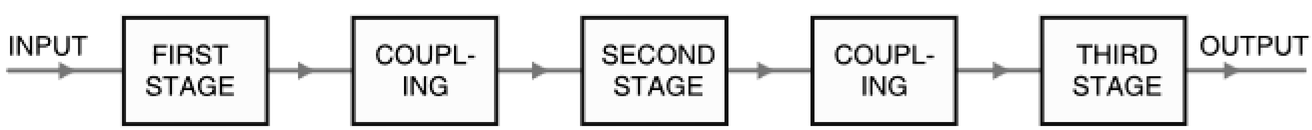
$$\frac{V_o}{V_s} = A_f = \frac{A}{1 + A\beta}$$

Fig.18 shows the block diagram of an amplifier stage with negative feedback applied. In this circuit, the proportion of the output voltage fed back to the input is given by β and the overall voltage gain will be given by:

$$Overall\ gain, G = \frac{V_o}{V_s}$$

1.2.4 Multi-stage amplifiers

Output of first stage is connected to the input of the second stage through a suitable coupling device and so on. In order to provide sufficiently large values of gain, it is frequently necessary to use a number of interconnected stages within an amplifier.



The overall gain of an amplifier with several stages (i.e. a multi-stage amplifier) is simply the product of the individual voltage gains. Hence:

$$AV = AV1 \times AV2 \times AV3, \text{ etc.}$$

Note, however, that the bandwidth of a multistage amplifier will be less than the bandwidth of each individual stage. In other words, an increase in gain can only be achieved at the expense of a reduction in bandwidth.

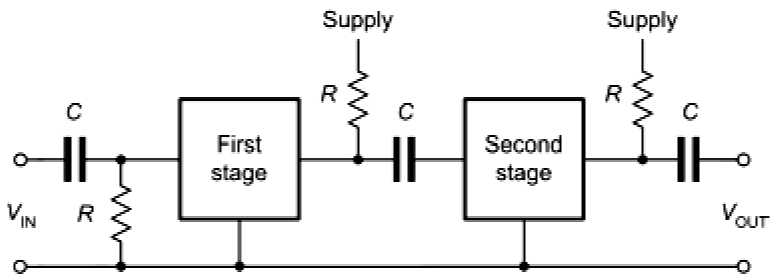
Types of coupling

Coupling devices transfer energy from one stage to the other.

(a) **In RC coupling**

Resistor (R) used as load impedance and capacitor (C) is used as the coupling element. The capacitor (C) connects the output of one stage to the input of the next stage which allows the AC signal while blocking the DC voltages. Since the DC resistance of R is high, the efficiency of the amplifier is decreased.

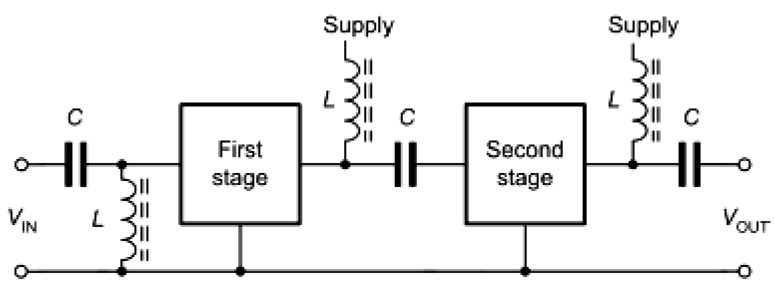
Disadvantage: i) Causes loss for the low frequency signals.
ii) Difficult to match the impedance from stage to stage



(b) **In L–C coupling**

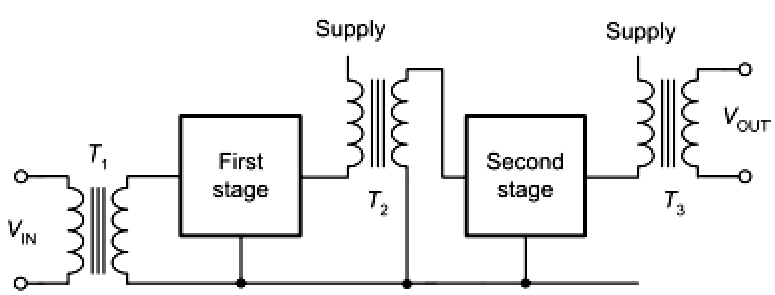
Inductance (L) as load impedance and capacitance(C) used as coupling elements. The capacitor connects the output of one stage to the input of the next stage which allows the AC signal while blocking the DC voltages. The impedance of coupling coil (L) depends on its inductance and signal frequency. Since the DC resistance of the coil (L) is low, the efficiency of the amplifier is increased.

Disadvantage: only used in RF and high-frequency amplifiers.



(c) **In transformer coupling**

Transformer is used as the coupling device. The transformer coupling provides two functions: i) to pass AC signal and blocking DC and ii) permits impedance matching.



Disadvantage: i) Coupling transformer is expensive and bulky
ii) Transformers tend to produce hum noise
iii) It has a poor frequency response